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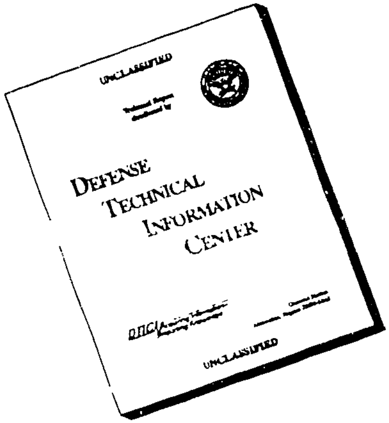

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THE OHIO STATE UNIVERSITY
RESEARCH FOUNDATION

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Report No. 3
RF Project 480

REPORT

By

THE OHIO STATE UNIVERSITY
RESEARCH FOUNDATION

COLUMBUS 10, OHIO

Cooperator AF CAMBRIDGE RESEARCH LABORATORIES
230 Albany Street, Cambridge 39, Mass.
Contract AF 19(604)-41

Investigation of FLUCTUATIONS OF STARLIGHT AND SKYLIGHT

Subject of Report Progress for the period April 1, 1952 to June 30, 1952

Submitted by J. Allen Hynek

Date July 25, 1952

ABSTRACT

Photometric and electronic equipment has been devised for the observation, primarily with the 12.5-inch refractor of the McMillin Observatory of The Ohio State University, of the brightness fluctuation and color fluctuation of stars, both in the daytime and nighttime sky, and of equivalent, or smaller, portions of the daytime sky, under a variety of meteorological conditions. The objective of the work is to provide the basic observations (and to analyze those made by other workers) which, it is hoped, will lead to a new tool for the study of the upper atmosphere.

The basic equipment has been purchased, or fabricated in the University shops, and is now in good operation. Other equipment intended for refinement of observations is still on order. Delivery time for specialized equipment is notoriously long.

The previous two quarterly reports were concerned with matters of instrument design, fabrication and procurement, testing and calibration. In the present report period these activities were continued, but the first consecutive observational results were obtained and analysed. The investigation of the literature was completed and submitted as a final draft for a separate Air Force technical report.

It has been established that an area of daytime sky, 0.3 square seconds of arc in area (and thus much smaller than the tremor disk of a star) is very much steadier than a star of comparable brightness at night. Determination of the upper limit of sky fluctuations awaits other instrumentation, but with the present basic photometric equipment,

if the tiny segment of the sky had one-tenth the fluctuation amplitude observed in a star, it would have been detected.

Stars have been recorded photoelectrically in the bright daylight, using d-c techniques, but the problem of fluctuation study is insuperable with the present equipment and will present grave difficulties even with the new equipment if one wishes to record the entire tremor disk of a star.

It appears that stars have an "aureole" about them which is detectable photoelectrically but not visually. Diaphragms which appear to admit the total visual image do not admit all of the light of a star. It may be possible to construct "isophotes" of a stellar tremor disk relating the radius of the disk to the mean total light contained within an area of that radius.

PERSONNEL AND ADMINISTRATION

There were no changes in personnel and no essential changes in administration of the contract. Mr. Protheroe was put on full-time status during the summer.

The only deficiency that hinders the full scope of the work is the slow delivery of equipment. Facilities at the University are adequate and space at the observatory and time at the telescope are sufficient. The telescope and accessories are in good condition.

With respect to the slow delivery of equipment, an attempt was made early in the contract period to procure an oscilloscope and a tape recorder from the undoubtedly large supply of such equipment within government laboratories. It proved impossible, however, to arrange for such a transfer of equipment, and after considerable delay, funds from the present contract were committed for its purchase. This accounts in part for the delay in obtaining equipment essential for the project.

COMMUNICATIONS

There was, during this report period, the usual amount of routine correspondence concerning equipment.

Dr. Hynek gave a colloquium (May 19, 1952) at the State University of Iowa, Physics Department, on the subject of stellar scintillation. Dr. Van Allen, chairman, and his staff all joined into a spirited discussion.

Dr. Heinz Fischer, of the Cambridge Research Laboratories, visited the McMillin Observatory in May for a review of progress to date.

Dr. Hynek attended the meetings of the American Astronomical Society at Victoria, B.C., June 25-28 and subsequently visited the Lick Observatory of the University of California, the Mt. Wilson and Palomar

Observatories, and the Lowell Observatory at Flagstaff, Arizona. He discussed the problem of stellar scintillation with numerous astronomers, especially with Dr. Kron and Dr. Eggen of the Lick Observatory, both of whom are well known for their photoelectric work.

He also visited the White Sands Proving Ground to see Dr. Clyde Tombaugh, who is in charge of optics design in the Flight Determination Laboratory. Tombaugh is acquainted with the problem of daytime "seeing" in connection with his work on the visual tracking of rockets.

Informal liaison was continued with Dr. Hall at the Naval Observatory, who is cooperating with us in similar work. Dr. Hall and his associates are attempting to determine the primary levels in the atmosphere at which scintillation effects occur.

All of the above conferences resulted in heightened interest in the problem.

STATEMENT OF PROBLEM AND METHODS OF ATTACK

The problem that concerns us in this work is the study of the fluctuations in brightness and in color of starlight and skylight, with special emphasis on daytime observations. The specific contract work is to devise and utilize equipment to record and analyze such fluctuations. The long-range purpose of such observations is to provide a possible basis for the study of upper atmospheric conditions from the ground.

Although much qualitative work has already been done by others (and of late a considerable amount of quantitative work also), this had never been collated and brought to bear on guiding future observations needed to attack the problem of the upper atmosphere.

Mr. Hosfeld completed a survey of the literature, and his report, comprising 55 typewritten pages, is ready for issue as a separate Air Force Technical Report.*

*A preliminary copy has been sent to Mr. Heinz Fischer, Air Forces Cambridge Research Laboratories.

A. Fluctuations of the Blue Sky

It is of considerable interest to check experimentally the short-range constancy of blue skylight. The daylight sky appears constant to the eye, of course, and one might think that this is because the eye takes in such a large area that any "point-to-point" variations are swamped out in the integrated light.

Goldstein and Hall and their respective associates at Naval Research Laboratory and the Naval Observatory reported that blue sky areas of

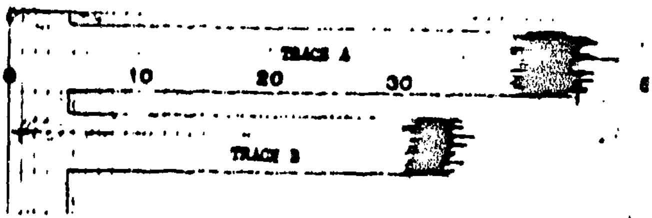
about 70,000 and 16 square seconds of arc, respectively, showed no detectable fluctuations. It still might be thought, however, that a veritable "point-source" portion of the sky, smaller than the tremor disk of a star, might show fluctuations similar to those of a star.

The present photometer has one diaphragm that admits but 0.3 square seconds of arc of sky. Accordingly, as soon as the equipment was ready, the search for such possible "point-source" fluctuations was made. The four traces of Fig. 1 illustrate that 0.3 square seconds of sky are very much "quieter" than a star (at night) having comparable brightness. The star was #6789 in the Yale Catalogue of Bright Stars ($4^m.44$, spectral type A0, altitude 43° in the northern part of the sky) and its record is shown in the top two traces (two slightly different dynode voltages). The bottom two traces are of 0.3 square seconds of blue sky at elevation 40° in the northern sky (the North Celestial Pole).

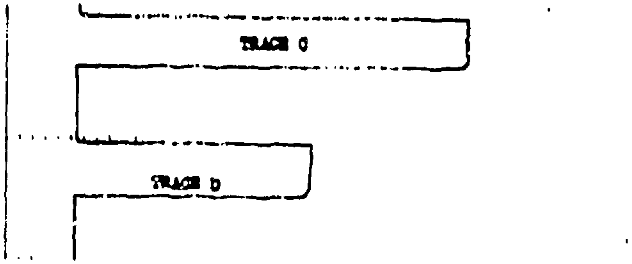
The very small fluctuations in the sky traces are very probably of instrumental origin. To establish this point, an artificial constant source was devised. This consisted of a d-c operated bulb enclosed in the optical system of the photometer, adjusted so as to give the same signal as that given by the very small portion of the daylight sky.

Fig. 2 shows, side by side, portions of a trace of the blue sky and of the light from the artificial source. Relatively high sensitivity was used. It is apparent that insofar as the present equipment is concerned, no high (relatively) frequency fluctuations in the blue sky are present.

Fig. 1. STAR TRACES VS. BLUE SKY TRACES



Star BS 6789, 4.44^m A0, at 43° Elevation in Northern Sky



0.6 Seconds Diameter Area of Blue Sky at 40° Elevation in Northern Sky

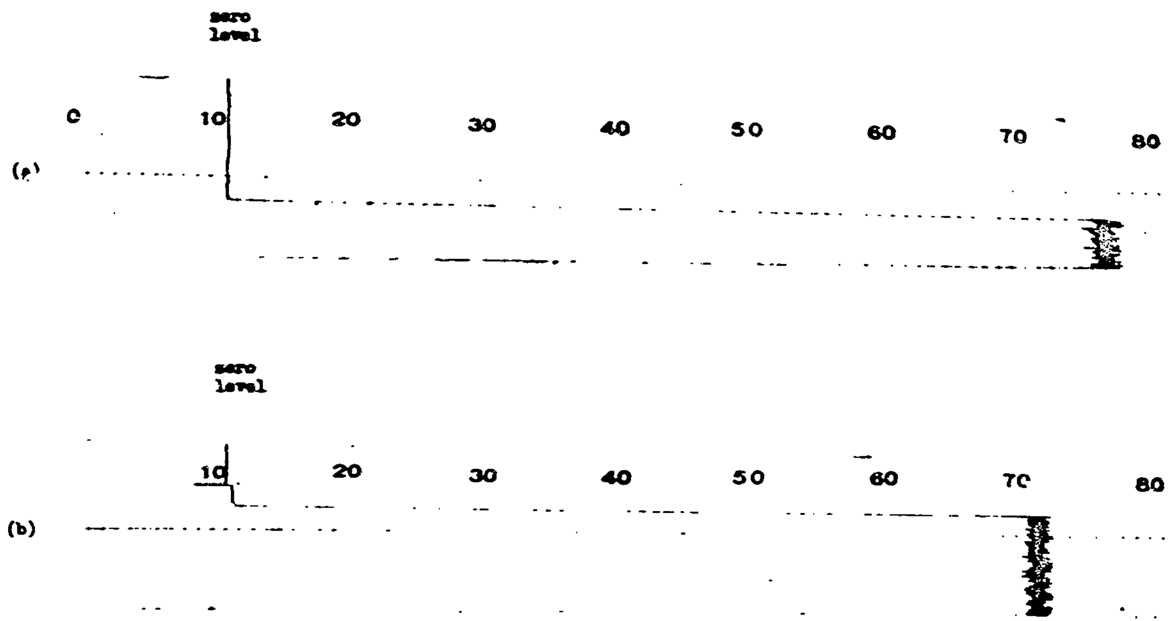


Fig. 2.

Sky Trace (a) vs. Trace of artificial Source (b)

Lower frequency components do s... to be present (not shown in Fig. 2), of the order of 10% and approximately 0.1 cps. These may arise from wisps of cloud and haze too thin to be detected by the eye.

The tentative conclusions that can be drawn from these observations are that the blue sky presents a relatively constant source or background as far as audio frequencies are concerned, and differs markedly in this respect from starlight.

B. Size and Gradient of Star Images

The daytime image of a star appears small to the eye, but there is strong evidence that this is deceptive, and that the outer "corona" of light in the star is lost to the eye because of lack of contrast with respect to the blue sky. This cannot be tested here until the new equipment arrives, but measures made on the size of nighttime stellar images are revealing.

It must be remembered that a refractor was used throughout, and that perfect achromatism is not possible in a refractor. That is, when the image is in focus in the yellow, an out-of-focus blue halo exists around the image. This will be true whenever a lens system is used and hence the following measures are included, not as indicating real size of a stellar tremor disk, but the telescopically distorted real tremor disk one has to "put up with" when refracting telescopes are used. The use of filters is, of course, called for, and these cut down the apparent size of the tremor disk very considerably and give an image which approximates the true tremor disk in that color.

A second magnitude star (type K5) was recorded successively through the 5-mm, 2-mm, 1-mm, 0.50-mm, 0.25-mm, and the 0.10-mm apertures which correspond, respectively, to 226, 90, 43, 17.5, 5.8, and 3.8 seconds of arc in diameter when used in the focal plane of the McMillin telescope.

With the 5-mm and 2-mm openings the recorded signal was the same, but decreased rapidly with smaller diaphragms, as tabulated below:

Diaphragm	Diam. in seconds of arc	% Change in signal (5-mm as ref.)	Noise*
5 mm	226	--	12.9
2 mm	90	0	12.9
1 mm	43	3.6	14.0
0.50 mm	17.5	16	13.4
0.25 mm	5.8	39	21.2
0.10 mm	3.8	68	57.9

* Percent of total signal represented by the noise.

Thus, though to the eye a star under average seeing conditions appears to subtend an angle of about 2 seconds of arc, the table above shows that the total spread of the image is actually about 50 seconds of arc. As soon as the admitting diaphragm is appreciably smaller than this, the total signal from the star is markedly decreased.

The recorded noise, on the other hand, increases markedly. This is most likely to be interpreted as the variable admittance of portions of the "corona" of the stellar image. Since scintillation is "true" noise in the star signal, the rise of this "false" noise will vitiate

any measures of actual scintillation unless adequately large diaphragms are used. This practice of using sufficiently large diaphragms is, of course, permissible at night, but in the daytime, the admittance of so much competing skylight tends to swamp out any star signal. Fortunately, as the previous section indicates, the blue sky background (actually, foreground, since the blue sky is close about us) contributes a sensibly constant d-c signal. This should make it possible to employ a wide band-pass amplifier which rejects the d-c component but admits all of the component frequencies of the stellar scintillation.

It was not anticipated at the start of this work that the "photo-electric" star image (without color filters) would be found to be so very much larger than the apparent visual image. Whereas the visual observer would surmise that the image he sees comprises 95% or more of the total light of the star, the photoelectric measures indicate that he does not see 20-30% of the light of the star.

This striking result must be rechecked carefully, and the measures repeated in different colors. The question of the total size of a tremor disk has a bearing on the accuracy of many types of astronomical observations. It will be of considerable interest to continue these observations and to devise, if possible, "isophotes" of a stellar tremor disk.

It is interesting to recall that in a preliminary draft of the proposal for this work just such measures were called for. The writer caused this to be struck out from the proposal submitted to the Air Force because he felt that no commitment could be made about an observation which seemed impossibly difficult to make.

If easures with the 12.5-inch refractor show promise, the 69-inch Perkins Observatory reflector will be used to study image sizes given by a large reflector.

"Isophotes" of stellar images would be of importance not only in basic astronomy, but also to the entire problem of star tracking.

C. Calibration of Diaphragms

Inasmuch as throughout the course of this work reference is made to the various diaphragms employed to admit starlight and skylight, it is important to establish with some accuracy the actual angular equivalence of these apertures, especially of the smaller ones.

These eight apertures were calibrated photoelectrically by determining the ratios of the signals from an artificial constant source given by the different apertures. The diameters of the diaphragms were also measured on a measuring engine. The photoelectric measurements are to be given preference because of the difficulty of taking into account minor edge irregularities and burrs which are readily seen in the eyepiece of the measuring engine. These data are summarized in the following table:

TABLE I

Aperture Calibration

Nominal Diameter in mm.	Diameter, Measuring Engine	Diameter, Photoelectric (5.0 mm = standard)	Seconds of Arc (Photo-electric)	Relative Area (Photo-electric)
5.0	5.03	5.03	226	140,000
2.0	2.01	2.00	90	22,000
1.0	0.99	0.95	43	5,000
0.50	0.44	0.39	17.5	840
0.25	0.15	0.13	5.8	95
0.10	0.11	0.084	3.8	39
0.050	too irregular to measure	0.032	1.4	5.8
0.025	"	0.013	0.6	1.0

D. Observations of Stars in the Daytime

The relatively large total size of the tremor disk of a star ma observations of a star in the daytime a formidable task, particularly if the total tremor disk is desired. Capella (mag. 0.21, type G0) is just barely detectable using the 5-mm diaphragm and only a 2 per cent change in total signal is noticed when the 1-mm opening is employed. In these measures a yellow filter was used for obvious reasons.

These preliminary results indicate that a more refined technique must be employed if the scintillation of daytime stars is to be faithfully recorded.

APPARATUS

Given below is a listing of apparatus now on hand and that which is on order.

On Hand

One laboratory-constructed d-c amplifier

Two Brush BL 932 d-c amplifiers

One Brush BL 202 Dual Channel Oscillograph

One Brown Recorder
(Property of McMillin Observatory)

One Atomic Instruments #306 High Voltage Supply
(Property of McMillin Observatory)

One General Radio 715-A d-c amplifier
(Property of McMillin Observatory)

One General Radio 762 B Vibration Analyzer

One Low Frequency Magnetic Tape Recorder
(On loan from the U. S. Naval Observatory)

One Fastax Camera
(On loan from Wright-Patterson Air Force Base)

On Order

One Kron-Hite Ultra Low Frequency Band Pass Filter #330-A
(Delivery promised: July 21)

One Tektronix Type 112 d-c Amplifier
(Delivery promised: Aug. 15)

One Kay Vibralyzer
(Delivery promised: Aug. 15)

One Dumont 322 Double Beam Oscilloscope
(Delivery promised: Aug. 20)

One Amplifier Corp. of America 821-FM Tape Recorder
(Delivery promised: Nov. 27)

As is obvious from the above, a considerable proportion of essential equipment is not yet on hand.

During this report period the photometer head was modified to incorporate a third (guiding) eyepiece so placed that visual observation of the star image is possible simultaneously with its photoelectric recording. This was found to be absolutely essential for the recording of star signals in the daytime.

THEORETICAL CONSIDERATIONS

We have been privileged to obtain a pre-publication copy of a paper by S. Chandrasekhar on stellar scintillation. Dr. Geoffrey Keller has studied this paper and has communicated to us the following comments:

"At your suggestion I have read Chandrasekhar's recent article entitled, 'A Statistical Theory of Stellar Scintillation.' I found it extremely interesting, and so have been moved to look into the matter in a little greater detail.

"From the observational point of view some sort of theory of stellar scintillation is highly desirable. One wishes to give significance to the observations which one can make at the telescope (shape and motion of shadow bands, frequency of pulsations, etc.) by associating them with material processes occurring in the atmosphere. In addition, however, there are several practical considerations. Suppose one has a nearly correct approximate physical theory of the origin of the scintillations (such as one based on the existence of a turbulent layer of air), then one should be able to predict the nature of events observed at the telescope in terms of the physical parameters of the theory (thickness and height of the layer, mean size of an eddy, mean fluctuation in density). One might then hope to reverse the process and use the observations to determine the parameters. Chandrasekhar has already made progress in this direction. The theory should also serve as a guide in showing what new types of observation might be made which would yield more precisely and unequivocally the significant physical parameters. One should not overlook the possible implications

concerning telescope design. For instance, we know that if seeing troubles were absent, resolution would be proportional to apertur . It appears at first glance that the effective resolution in the presence of poor seeing might be independent of aperture for large telescopes. I do not know of any systematic observational data proving or disproving this point. I am not convinced that it follows theoretically from existing hypotheses. A clarification would be desirable.

"Concerning existing theories, I believe the following to be true: The older concepts are based on the notion that the atmosphere contains an inversion surface at a height of several kilometers. The surface was thought to be corrugated in an irregular fashion. An individual corrugation was considered roughly as a cylindrical refracting surface. Light from a star at the zenith passing through such a surface would be concentrated at a focal line at a distance below equal to the focal length of the corrugation. To account for the spacing of the shadow bands, such corrugations must be 5 to 10 cm in width. The principal objections to this theory are that it does not explain scintillation in color, it requires an improbably large difference in density between the two sides of the refracting layer, and the cylindrical refracting surfaces might not have enough resolving power to produce sharp focal lines (bands) at the distance of the earth's surface.

"These three objections have been emphasized by Little (M.N. 111, 289 (1951)). Following ideas of Booker and Gordon he suggests that the single refracting surface be replaced by a layer of turbulent air 0.2 km thick. In this layer one places vertical convective elements having widths of 5 cm and densities (and hence refractive indices) differing slightly from the mean. Due to the long light path through these elements (0.2 km?) they can produce an appreciable advancement or retardation of the wave front even though the difference in their density from the mean is very much less than the per cent or so required by the single layer theory. Little implies that only a few such elements would be traversed by an incoming light ray, but this is scarcely credible, since it requires that convective elements 100 meters long and only 5 cm wide be lined up accurately parallel to the incoming rays. Even if this were the case for stars at the zenith, it would not be so for stars at any distance from the zenith.

"Chandrasekhar handles this problem much more neatly. He assumes that the disturbing elements are roughly spherical and have a diameter of the order of 10 cm. (The elements could equally well be assumed to be cylinders with their long axes parallel to one another and horizontal). His whole layer is about 100 meters thick. Light from a star at the zenith would thus pass through some thousand eddies. He shows that with a plausible density fluctuation from the mean the accumulated statistical retardation

or advancement of the wave front is sufficient to give scintillation effects. Moreover, the width of the average corrugation in the wave front is also about 10 cm, which is that required to account for the separation of shadow bands.

"Chandrasekhar does not say much about what happens to the light after it leaves the turbulent layer, but implies that it travels in geometrical rays perpendicularly away from the wave front just below the layer. In this way he calculates the angular diameter of the average tremor disk. He also computes the average amplitude of a corrugation in the wave front just below the layer and shows this to be 1800 Å. He states that this accounts for color scintillation, but on the basis of the geometrical propagation theory it does not. It is the difference in amplitude for two colors which is important. For green and red light this difference would be 18 Å, and would give a difference in angle of only 0.004 second of arc, which would scarcely be observable.

"It seems to me that Chandrasekhar's theory gives the best available theory of the physical origin of scintillation, but that a more elaborate theory must be used to connect the nature of the wave front which strikes the surface of the earth and that which leaves the lower side of the turbulent layer. Since the size of one average corrugation in the wave front emerging from the layer is 10 cm, at a distance of 4 km a ray of light of λ 6000 will be spread laterally over at least 8 cm, which in itself would smear the shadow bands. On the other hand, there are interference effects occurring in a statistical fashion between rays originating from different corrugations, and these must be considered.

"A suitable treatment of this propagation problem has evidently been given by Booker, Ratcliffe and Shinn (Phil. Trans. Royal Soc. A, 242, 579 (1950)). I have not had a chance to look at this paper, but believe that I have reproduced the essential parts. It is based on the Fresnel theory of diffraction. It turns out that the wave front which strikes the earth's surface has corrugations of the same widths as those in the emergent front, but the amplitudes vary in a different way with the width, and with color. The last result is important, and (as Little has already pointed out) should account for color scintillation.

"I think this last type of analysis will enable us to explain the behavior of the shadow bands in terms of the turbulent layer, and an analysis of the bands should give many properties of the layer. The fluctuations in the amount of energy received by a circular area (equal to that of the telescope objective) of the wave front striking the earth are equal to the fluctuations of the integrated light received by a phototube. This is what Hall et al

have been trying to measure. (It occurs to me that the Fabry lens setup which we have been using for measuring such time fluctuations in intensity may be undesirable. Shadow bands sweeping across the telescope objective mean shadow bands sweeping across the photosensitive surface).

"When it comes to predicting the properties of the stellar image in the focal plane of the telescope (to calculate the size of the tremor disk, for instance), it is necessary to use Fraunhofer diffraction theory, starting with the properties of the wave front incident on the surface of the earth. I believe this is feasible. I have not seen any work in this direction by other people."

Dr. Keller is now himself looking into certain theoretical aspects of the problem and will probably prepare a paper on it to be issued as a Technical Report.

CONCLUSIONS

The program is progressing well. The relatively long stage of apparatus construction is essentially over, and consecutive observations are being obtained. However, slow delivery of certain items is holding up some observations that should now logically be made.

Measures of the blue sky have been made and even very small areas have been found remarkably constant in comparison, that is, with a star image.

Star images, on the other hand, have been found to have considerably larger tremor disks photoelectrically than they appear to have visually.

Future Work

The following items are scheduled for attack and they will be pursued as the weather and the arrival of necessary equipment permit:

(1) An attempt to define a meaningful upper limit to "sky noise." Sky noise here is defined as any fluctuations over and beyond instrumental noise, regardless of the physical cause.

(2) Determination of the stellar magnitude of the blue sky under various conditions.

(3) Observations of the frequencies in the daytime scintillation of stars, in various colors.

(4) Further study of the structure of a stellar tremor disk under a variety of meteorological conditions.

Investigator Date

Supervisor J. Allen Hynek Date Aug. 15, 1952

For The Ohio State University Research Foundation

Executive Director [illegible] Date [illegible]

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